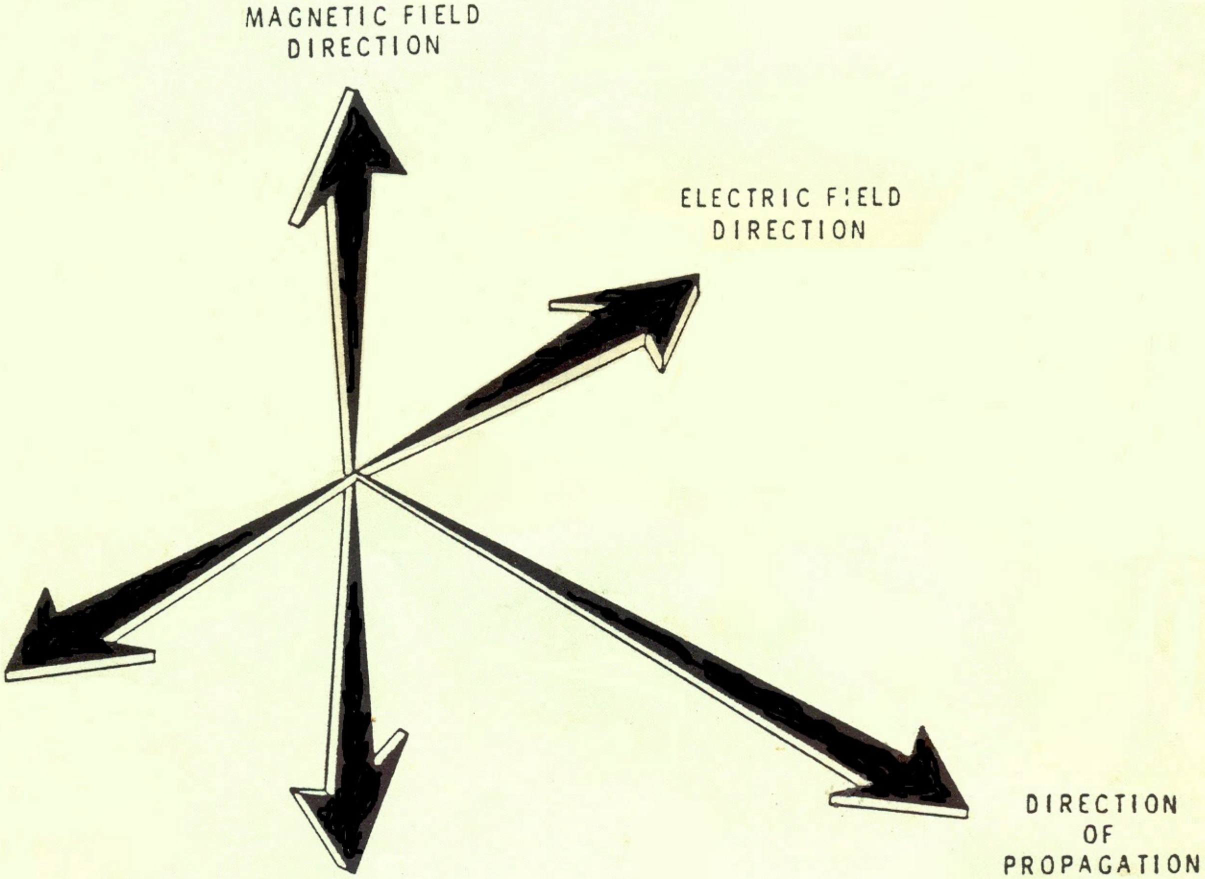
WAVE PROPOGATION, TRANSMISSION LINES, AND ANTENNAS



Polarization of an electromagnetic wave.

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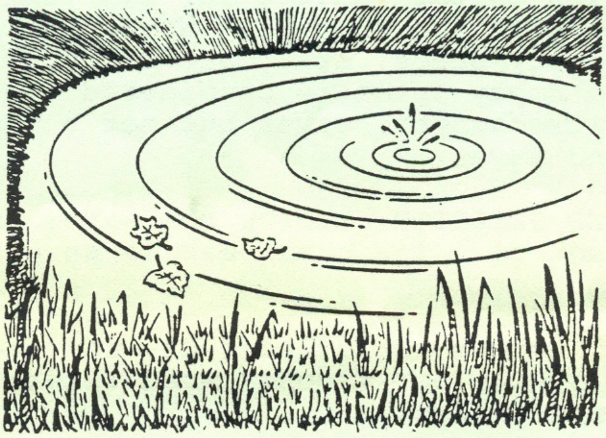
SUMMARY
WAVE PROPAGATION

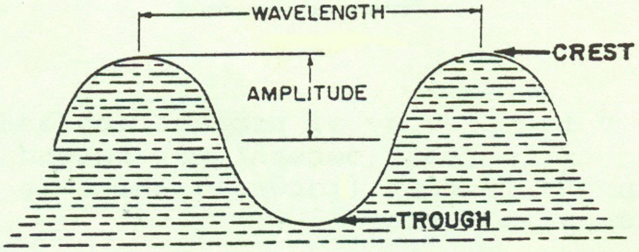
WAVE PROPAGATION is an invisible force that enables man to communicate over long distances. Wave transmission can take many forms, such as LIGHT, SOUND, and RADIO.

LIGHT is a form of wave motion that can be seen. Heat cannot be seen, but can be felt. Radio waves cannot be seen or felt.

WAVE MOTION can be seen in action by throwing a pebble into a pool of still water. The ripples that move toward the edge of the pool demonstrate the propagation theory.

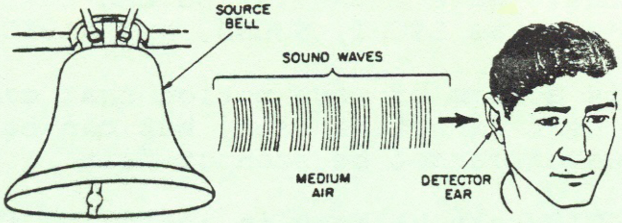


THE TRANSVERSE WAVE is a type of wave motion. Radio, light, and heat waves are examples of transverse waves.



THE LONGITUDINAL WAVE is another type of wave motion. The sound wave is the only example of a longitudinal wave given in this text.

SOURCE, MEDIUM, AND DETECTOR (RECEIVER) are the three requirements for all wave motion.



A SOURCE can be anything that emits or expends energy (waves).

THE MEDIUM is the vehicle for carrying waves from one point to another. Water, air, metal, empty space, etc., are examples of a medium. Empty space is considered a medium for electromagnetic waves but not a medium for sound waves.

THE SOUND DETECTOR absorbs the waves emitted by the source. The human ear is an example of a detector.

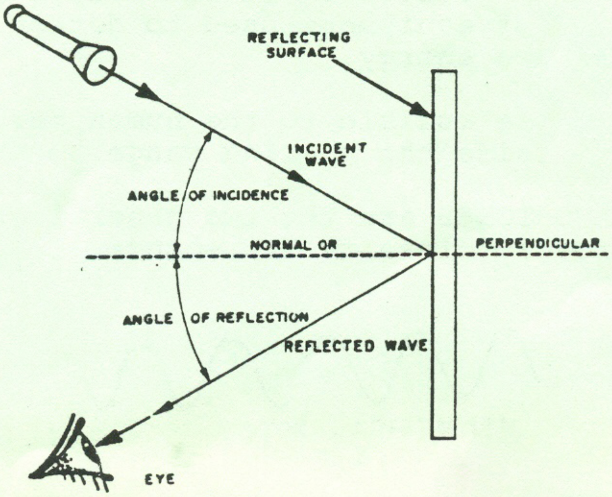
HERTZ, which is abbreviated Hz, is used in lieu of "cycle per second" when referring to radio frequencies.

VELOCITY OF PROPAGATION is the speed (or rate) at which the crest of a wave moves through a medium. Velocity can be calculated by using the formula:

$$\boxed{v = \lambda f}$$

Where v is velocity of propagation and is expressed in feet (meters) per second, λ is wavelength in feet (meters), and f is frequency in hertz.

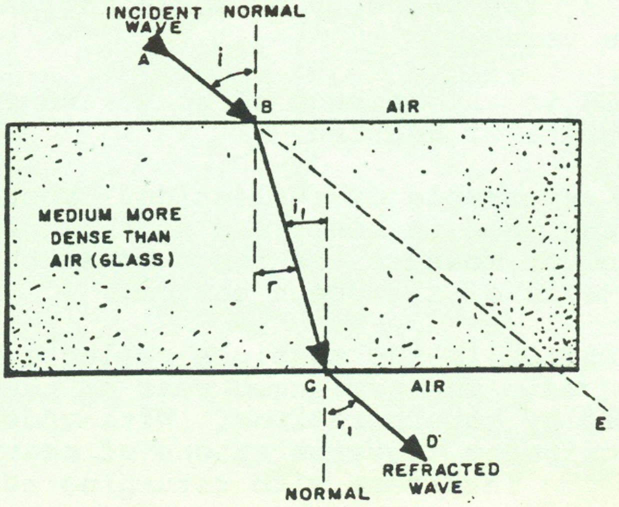
REFLECTION occurs when a wave strikes an object and bounces back (toward the source). The wave that moves from the source to the object is called the INCIDENT WAVE, and the wave that moves away from the object is called the REFLECTED WAVE.



THE LAW OF REFLECTION states:

The angle of incidence is equal to the angle of reflection.

REFRACTION occurs when a wave traveling through two different mediums passes through the BOUNDARY of the mediums and bends towards or away from the NORMAL.

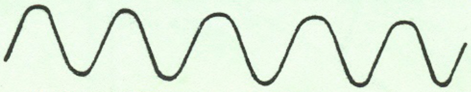


DIFFRACTION can account for the ability of the AM radio waves to travel over the opposite side of a mountain while FM and TV signals are blocked.

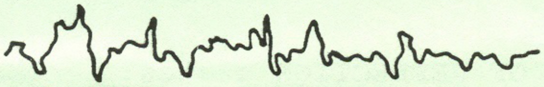
THE DOPPLER EFFECT is the apparent change in frequency of a source as it moves toward or away from a detector. It can affect the operation of equipment used to detect and measure wave energy.

SOUND can be audible to the human ear or it can be outside the hearing range.

NOISE AND TONES are the two general groups that broadly classify ALL sounds.



(A) MUSICAL NOTE



(B) NOISE

PITCH, INTENSITY, AND QUALITY are the three basic characteristics of sound. Pitch describes the frequency of sound. Intensity describes how much energy is transmitted. Quality enables us to distinguish one sound from another.

THE DENSITY OF A MEDIUM, TEMPERATURE, AND ATMOSPHERIC PRESSURE affect the velocity of sound. If temperature, density, or pressure increases, the velocity of sound increases and vice versa.

ACOUSTICS is the science of sound and relates to the sense of hearing.

ECHO is an example of reflection. Sound echoes are used in sonar and depthfinders to determine or measure the range of an object or the depth of the ocean bottom.

REVERBERATION is the multiple reflections of sound waves. The prolonged roar of thunder is caused by reverberations. With underwater sound equipment, reverberations of nearby objects may interfere with returning echoes from actual targets.

INTERFERENCE occurs when two waves move simultaneously through a medium. They can interfere constructively, destructively, or produce a resultant of zero.

RESONANCE occurs when an object vibrates (or resonates) at its natural frequency. When different frequencies are produced inside a cavity, the sound from the cavity sounds louder at its resonant frequency than at all other frequencies.

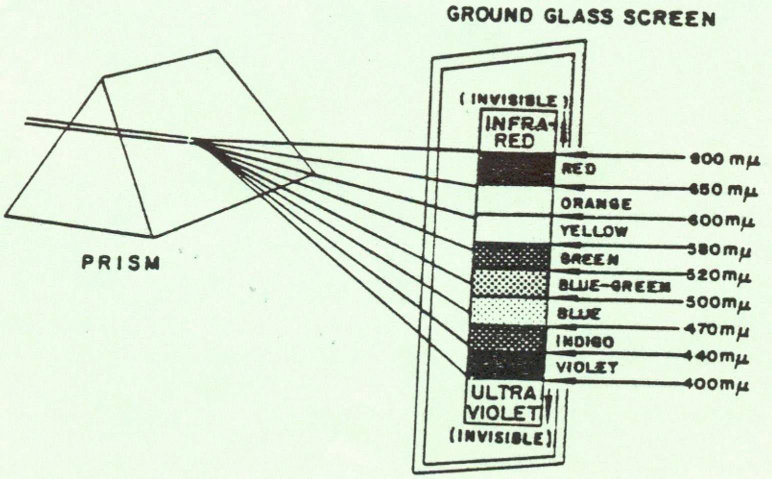
NOISE is any disturbance that distracts from or distorts the quality of sound.

A PHOTON is the smallest unit of radiant energy that makes up light waves and radio waves.

ANGSTROM (A) units are used for measuring the wavelength of light. One angstrom = 10^{-10} meters.

THE VISIBLE SPECTRUM contains all the colors between infrared and ultraviolet. INFRARED and ULTRAVIOLET are invisible to the human eye.

THE PRIMARY COLORS of light are red, green, and blue. These primaries can be mixed to make any color between red and violet. If the three colors are mixed equally they produce white light.



THE COMPLEMENTARY COLORS of light are magenta, yellow, and cyan. They are produced by mixing any two of the primary colors together in overlapping beams.

THE SPEED OF LIGHT in empty space is considered to be 186,000 miles per second (or 300,000,000 meters per second). This speed varies in different mediums, but the constant of 186,000 miles per second is always used as the speed of light.

SUMMARY
RADIO WAVE PROPAGATION

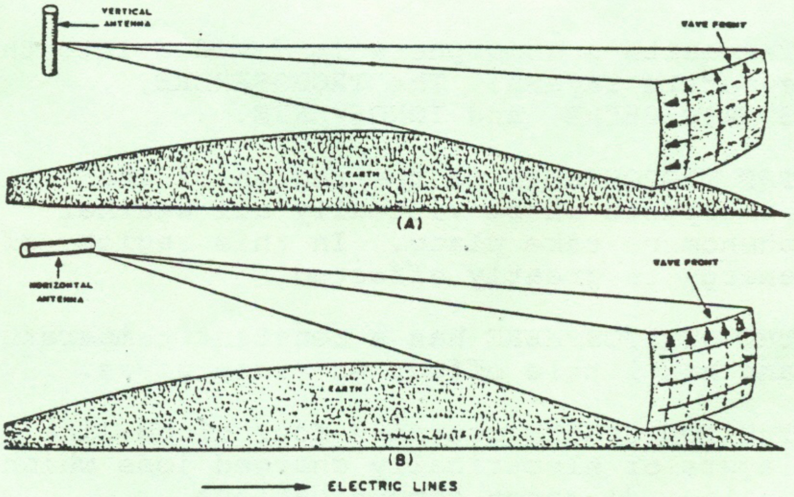
THE INDUCTION FIELD contains an E field and an H field and is localized near the antenna. The E and H fields of the induction field are 90 degrees out of phase with each other.

THE RADIATION FIELD contains E and H fields that are propagated away from the antenna into space in the form of electromagnetic waves. The E and H fields of the radiation field are in phase with each other.

A HARMONIC FREQUENCY is any frequency that is a whole number multiple of a smaller basic frequency. For example, a radio wave that is transmitted at a fundamental frequency of 3000 hertz can have a second harmonic of 6000 hertz, a third harmonic frequency of 9000 hertz, etc., transmitted at the same time.

A VERTICALLY POLARIZED antenna transmits an electromagnetic wave with the E field perpendicular to the earth's surface.

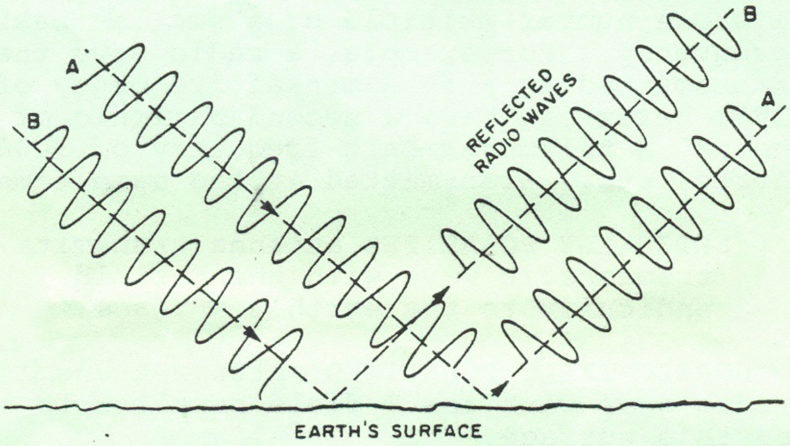
A HORIZONTALLY POLARIZED antenna transmits a radio wave with the E field parallel to the earth's surface.



A WAVEFRONT is a small section of an expanding sphere of radiated energy and is perpendicular to the direction of travel from the antenna.

RADIO WAVES are electromagnetic waves that can be reflected, refracted, and diffracted in the atmosphere in a similar manner to light and heat waves.

REFLECTED RADIO WAVES are waves that have been reflected from a surface and are 180 degrees out of phase with the initial wave.



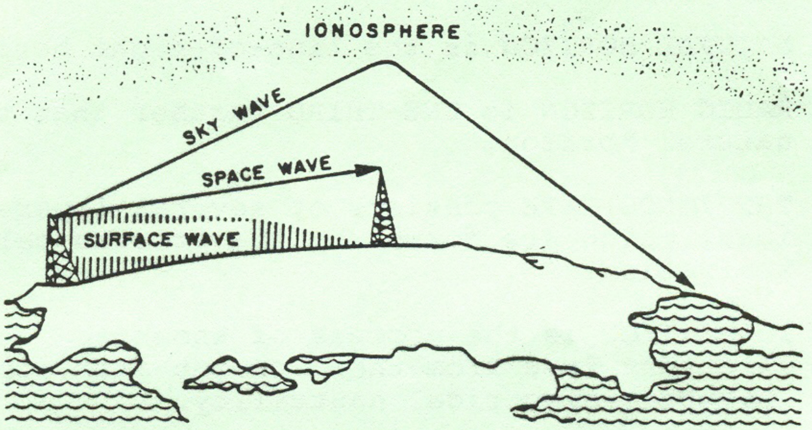
The earth's atmosphere is divided into three separate layers: The TROPOSPHERE, STRATOSPHERE, and IONOSPHERE.

THE TROPOSPHERE is the region of the atmosphere where virtually all weather phenomena take place. In this region, rf energy is greatly effected.

THE STRATOSPHERE has a constant temperature and has little effect on radio waves.

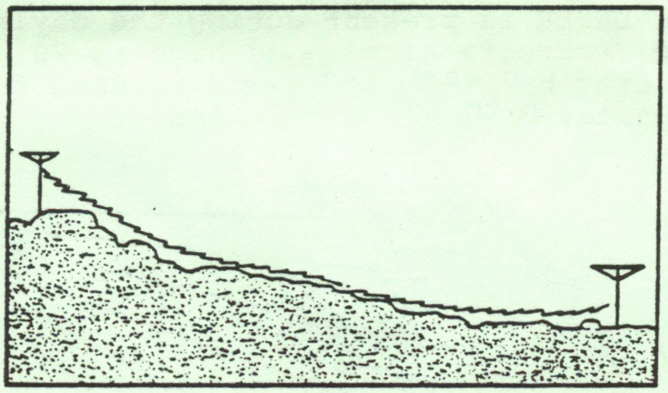
THE IONOSPHERE contains four cloud-like layers of electrically charged ions which aid in long distance communications.

GROUND WAVES and SKY WAVES are the two basic types of radio waves that transmit energy from the transmitting antenna to the receiving antenna.

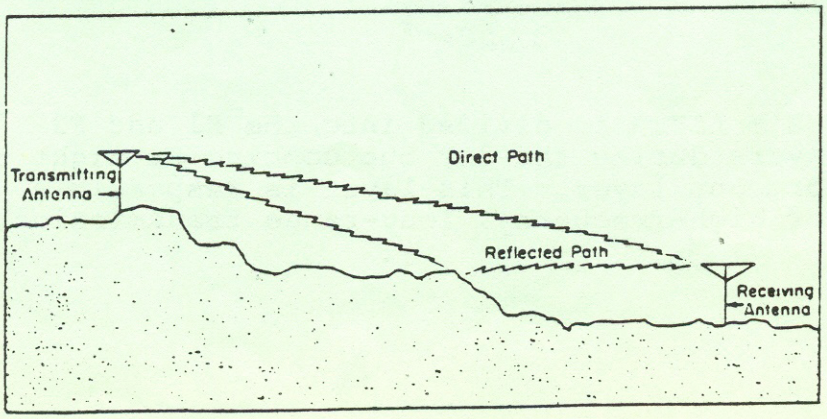


GROUND WAVES are composed of two separate component waves which are the SURFACE WAVE and the SPACE WAVE.

SURFACE WAVES travel along the contour of the earth by diffraction.



SPACE WAVES can travel through the air directly to the receiving antenna or can be reflected from the surface of the earth.



SKY WAVES, often referred to an ionospheric waves, are radiated in an upward direction and returned to earth at some distant location because of refraction.

NATURAL HORIZON is the line-of-sight horizon.

RADIO HORIZON is ONE-THIRD farther than the natural horizon.

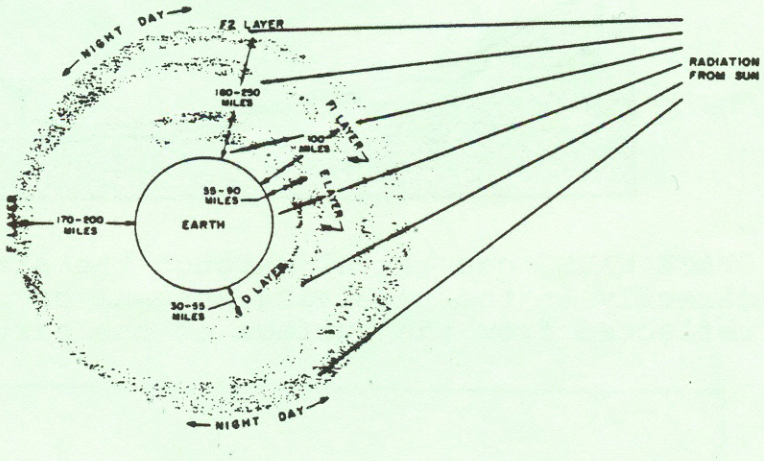
THE IONOSPHERE consists of several layers of ions, which are formed by the process called ionization.

IONIZATION is the process of knocking electrons free from their parent atom, thus upsetting electrical neutrality.

RECOMBINATION is the opposite of ionization; that is, the free ions combine with positive ions, causing the positive ions to return to their original neutral atom state.

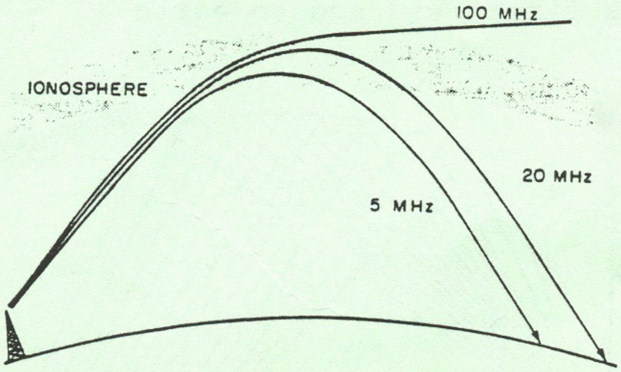
THE D LAYER is the lowest region of the ionosphere and refracts signals of low frequencies back to earth.

THE E LAYER is present during the daylight hours; refracts signals as high as 20 megahertz back to earth; and is used for communication up to 1500 miles.

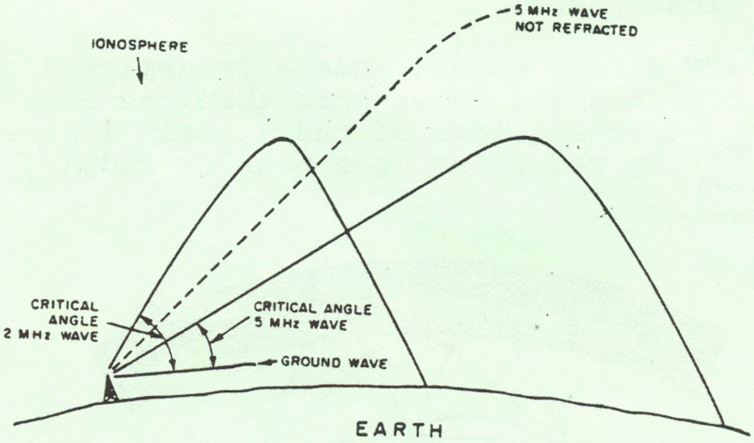


THE F LAYER is divided into the F1 and F2 layers during the day but combine at night to form one layer. This layer is responsible for high-frequency, long-range transmission.

THE CRITICAL FREQUENCY is the maximum frequency that a radio wave can be transmitted vertically and still be refracted back to earth.

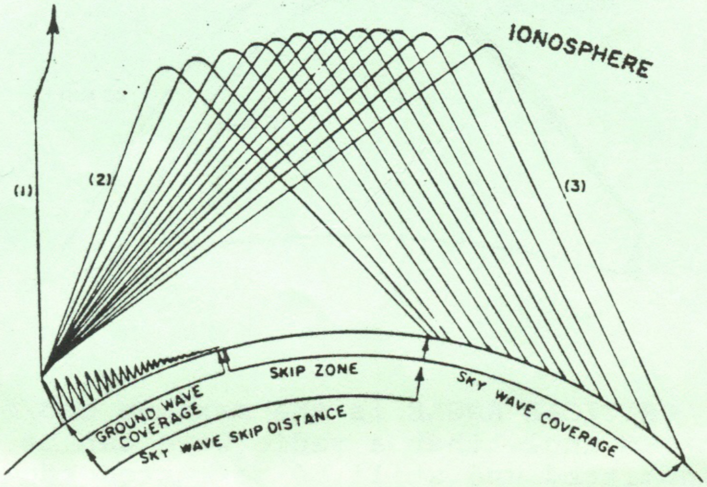


THE CRITICAL ANGLE is the maximum and/or minimum angle that a radio wave can be transmitted and still be refracted back to earth.



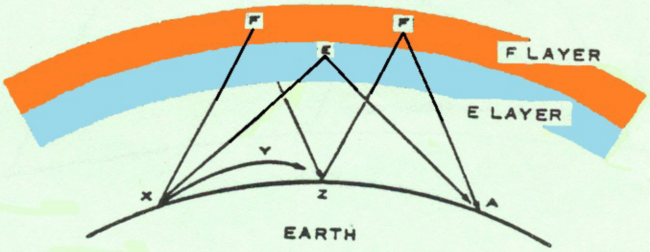
SKIP DISTANCE is the distance between the transmitter and the point where the sky wave first returns to earth.

SKIP ZONE is the zone of silence between the point where the ground wave becomes too weak for reception and the point where the sky wave is first returned to earth.



FADING is caused by variations in signal strength, such as absorption of the rf energy by the ionosphere.

MULTIPATH FADING occurs when a transmitted signal divides and takes more than one path to a receiver and some of the signals arrive out of phase resulting in a weak or fading signal.

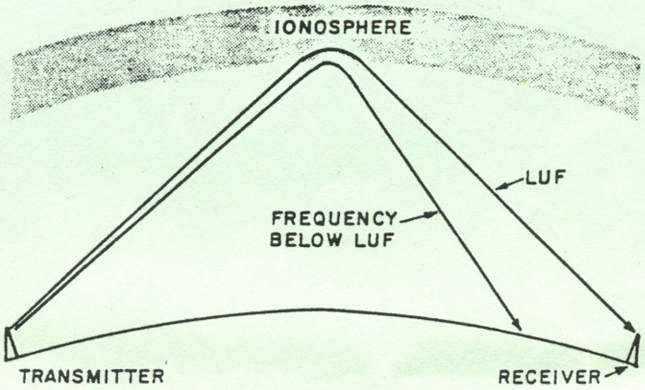


Some TRANSMISSION LOSSES that affect radio-wave propagation are ionospheric absorption, ground reflection, and free-space losses.

ELECTROMAGNETIC INTERFERENCE (emi), both natural and man-made, interfere with radio communications.

THE MAXIMUM USABLE FREQUENCY (muf) is the highest frequency that can be used for communications between two locations at a given angle of incidence and time of day.

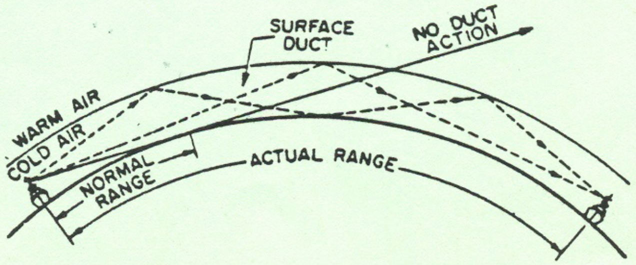
THE LOWEST USABLE FREQUENCY (luf) is the lowest frequency that can be used for communications between two locations.



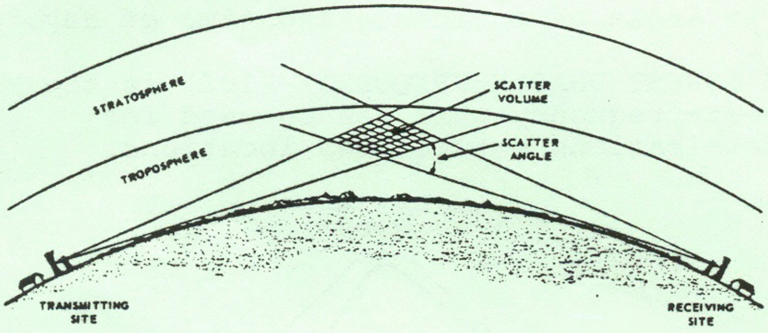
OPTIMUM WORKING FREQUENCY (fot) is the most practical operating frequency and the one that can be relied on with the least amount of problems.

PRECIPITATION ATTENUATION can be caused by rain, fog, snow, and hail; and can affect overall communications considerably.

TEMPERATURE INVERSION causes channels, or ducts, of cool air to form between layers of warm air, which can cause radio waves to travel far beyond the normal line-of-sight distances.



TROPOSPHERIC PROPAGATION uses the scattering principle to achieve beyond the line-of-sight radio communications within the troposphere.



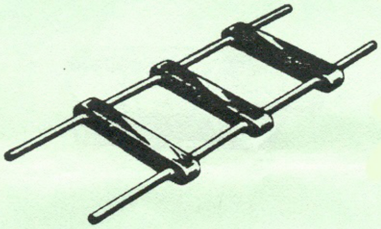
SUMMARY
PRINCIPLES OF TRANSMISSION LINES

TRANSMISSION LINES are devices for guiding electrical energy from one point to another.

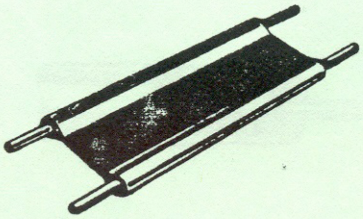
INPUT IMPEDANCE is the ratio of voltage to current at the input end of a transmission line.

OUTPUT IMPEDANCE is the ratio of voltage to current at the output end of the line.

TWO-WIRE OPEN LINES are parallel lines and have applications as power line, rural telephone line, and telegraph line. This type of line has high radiation losses and is subject to noise pickup.

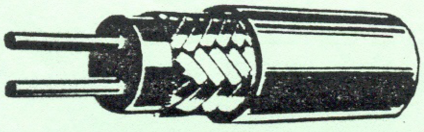


TWIN LEAD has parallel lines and is most often used to connect televisions to their antennas.

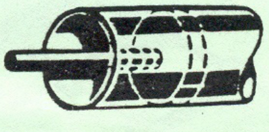


TWISTED PAIR consists of two insulated wires twisted together. This line has high insulation loss.

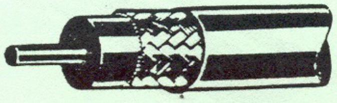
SHIELDED PAIR has parallel conductors separated by a solid dielectric and is surrounded by copper braided tubing. The conductors are balanced to ground.



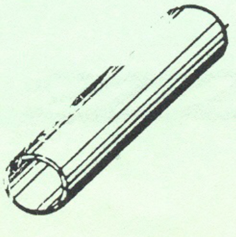
RIGID COAXIAL LINE contains two concentric conductors insulated from each other by spacers. Some rigid coaxial lines are pressurized with an inert gas to prevent moisture from entering. High-frequency losses are less than with other lines.



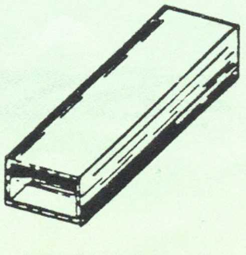
FLEXIBLE COAXIAL LINES consist of an inner conductor which is flexible and a concentric outer conductor of metal braid. The two are separated by a continuous insulating material.



WAVEGUIDES are hollow metal tubes used to transfer energy from one point to another. The energy travels slower in a waveguide than in free space.



CYLINDRICAL



RECTANGULAR

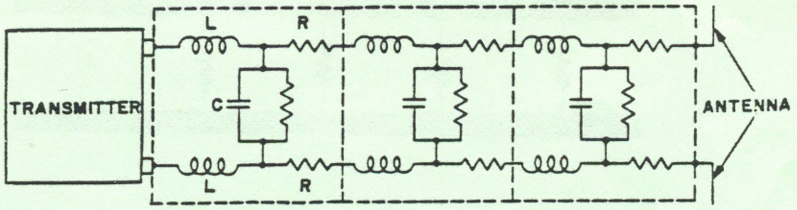
COPPER LOSSES can result from power (l R) loss, in the form of heat, or skin effect. These losses decrease the conductivity of a line.

DIELECTRIC LOSSES are caused by the heating of the dielectric material between conductors, taking power from the source.

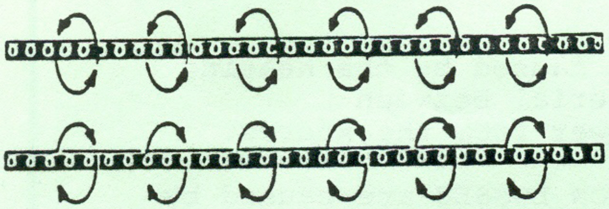
RADIATION AND INDUCTION LOSSES are caused by part of the electromagnetic fields of a conductor being dissipated into space or nearby objects.

A transmission line is either electrically LONG or SHORT if its physical length is not equal to 1/4 for the frequency it is to carry.

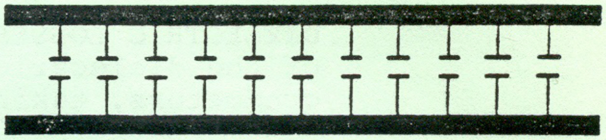
LUMPED CONSTANTS are theoretical properties (inductance, resistance, and capacitance) of a transmission line that are lumped into a single component.



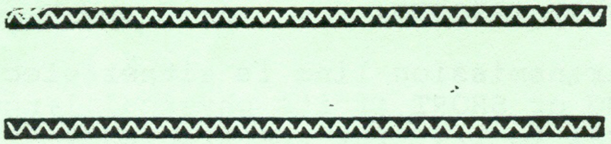
DISTRIBUTED CONSTANTS are constants of inductance, capacitance, and resistance which are distributed along the transmission line.



INDUCTANCE

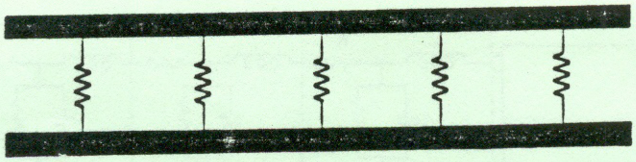


CAPACITANCE

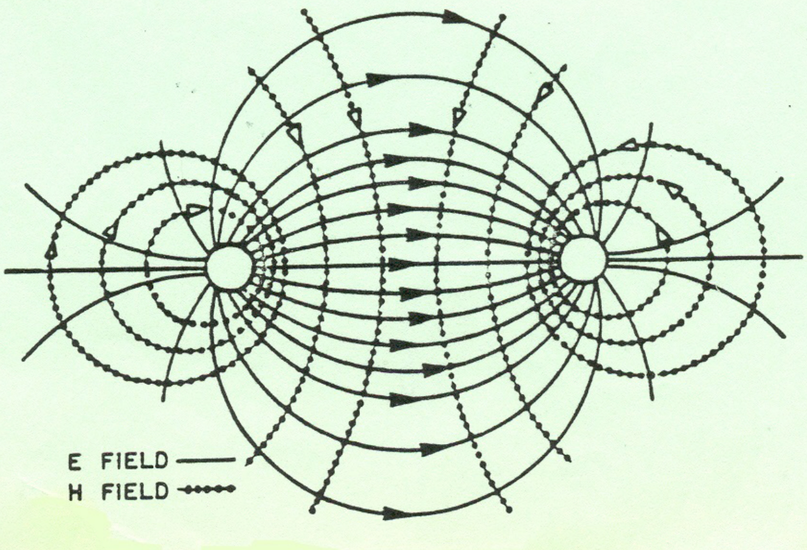


RESISTANCE

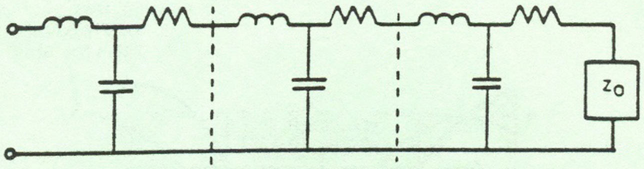
LEAKAGE CURRENT flows between the wires of a transmission line through the dielectric. The dielectric acts as a resistor.



An ELECTROMAGNETIC FIELD exists along transmission line when current flows through it.



CHARACTERISTIC IMPEDANCE, Z , is the ratio of E to I at every point along the line. For maximum transfer of electrical power, the characteristic impedance and load impedance must be matched.



The VELOCITY at which a wave travels over a given length of transmission line can be found by using the formula:

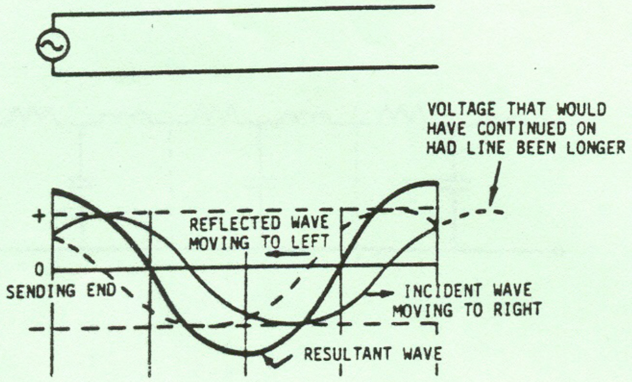
$$V = \frac{D}{\sqrt{LC}}$$

A transmission line that is not terminated in its characteristic impedance is said to be FINITE.

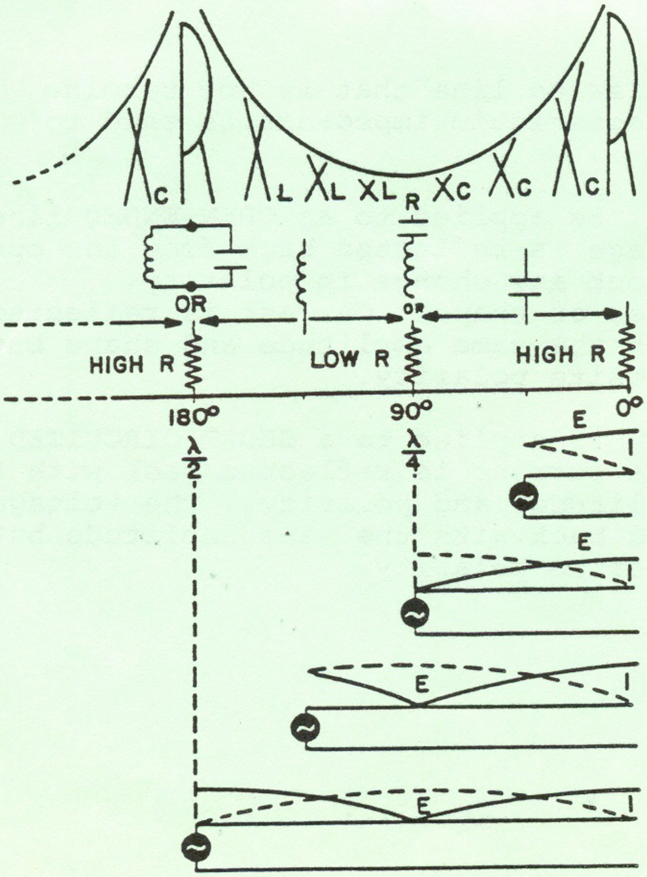
When D.C. is applied to an OPEN-ENDED line, the voltage is reflected back from the open end without any change in polarity, amplitude, or shape. Current is reflected back with the same amplitude and shape but with opposite polarity.

When D.C. is applied to a SHORT-CIRCUITED line, the current is reflected back with the same amplitude, and polarity. The voltage is reflected back with the same amplitude but with opposite polarity.

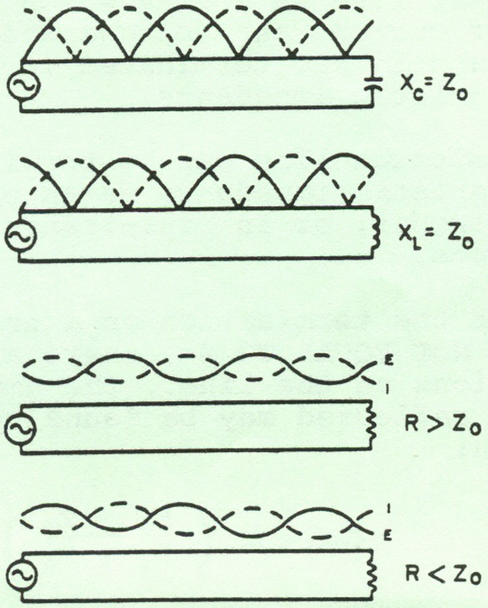
When A.C. is applied to an OPEN-END line, voltage is always reflected back in phase with the incident wave and current is reflected back out of phase.


VOLTAGE THAT WOULD HAVE CONTINUED ON HAD LINE BEEN LONGER
+
REFLECTED WAVE MOVING TO LEFT
0
SENDING END
INCIDENT WAVE MOVING TO RIGHT
-
RESULTANT WAVE

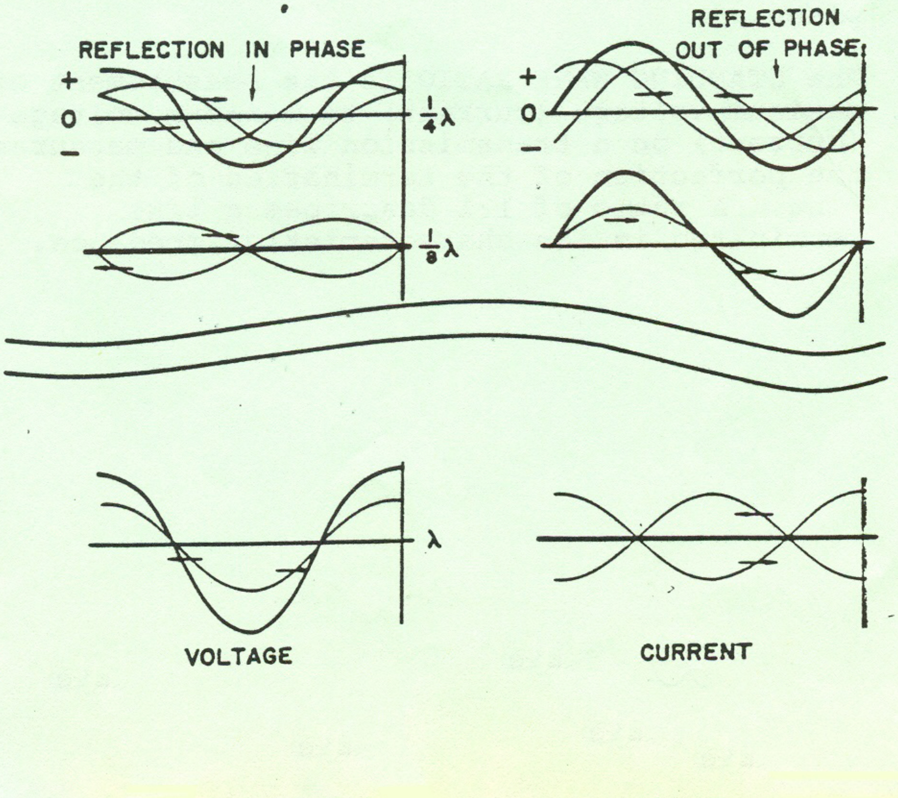
On an open-ended resonant line, and at all odd 1/4 points, the voltage is minimum, the current is maximum, and the impedance is minimum. At all even 1/4 points, the voltage is maximum, the current is minimum and the impedance is maximum.



There are a variety of TERMINATIONS for rf lines. Each termination has an effect on the standing waves on the line.



When A.C. is applied to a SHORT-CIRCUITED line, voltage is reflected in opposite phase while current is reflected in phase.



A NONRESONANT line is one which has NO STANDING WAVES of current and voltage and is either infinitely long or terminated in its characteristic impedance.

A RESONANT line is a line which has STANDING WAVES of current and voltage and is of finite length and is NOT terminated in its characteristic impedance.

A transmission line can be terminated in its characteristic impedance as an open- or short-circuit, or in capacitance or inductance.

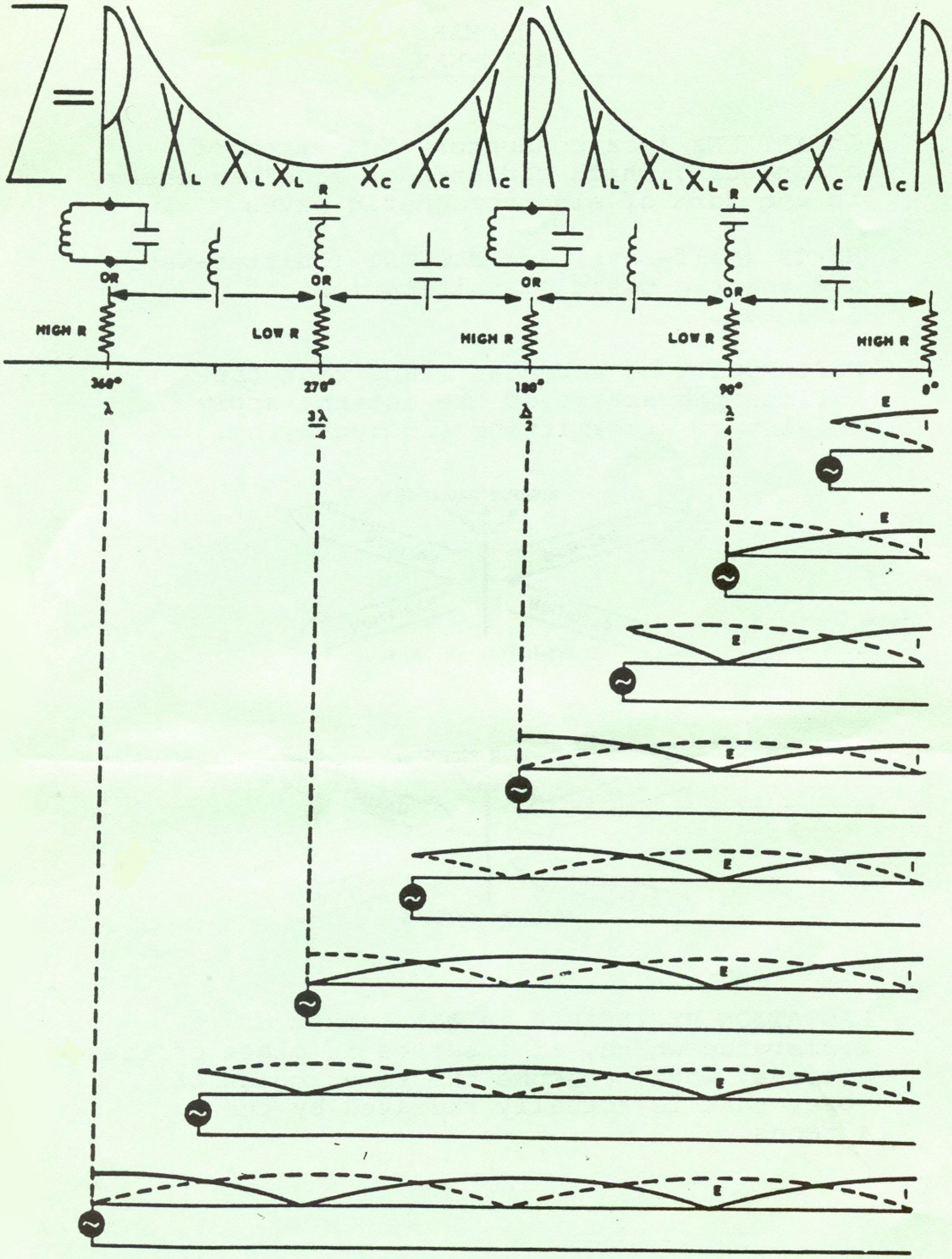
Whenever the termination on a transmission line is NOT EQUAL TO Z , there are reflections on the line. The amount of voltage reflected may be found by using the equation:

$$E_R = E_i \left(\frac{R_L - Z_o}{R_L + Z_o} \right)$$

When the termination on a transmission line EQUALS Z , there is NO reflected voltage.

The measurement of standing waves on a transmission line yields information about operating conditions. If there are NO standing waves, the termination for that line is correct and maximum power transfer takes place.

The STANDING WAVE RATIO is the measurement of maximum voltage (current) to minimum voltage (current) on a transmission line and measures the perfection of the termination of the line. A ratio of 1:1 describes a line terminated in its characteristic impedance.



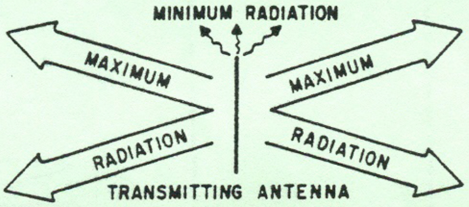
—Voltage, current, and impedance on open line.

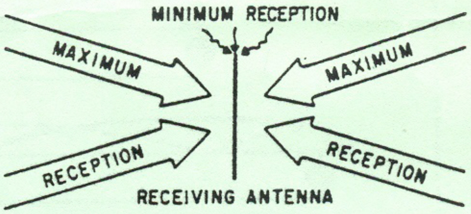
SUMMARY
ANTENNAS

An ANTENNA is a conductor, or system of conductors, which radiates or receives energy in the form of electromagnetic waves.

HERTZ (half-wave) and MARCONI (quarter-wave) are the two basic classifications of antennas.

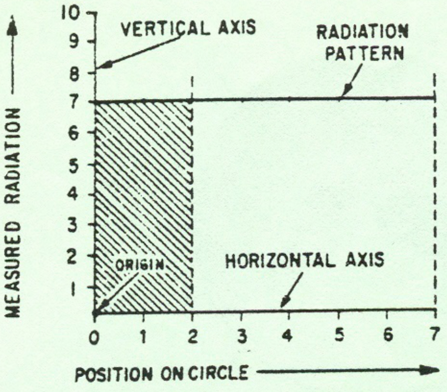
RECIPROCITY of antennas means that the various properties of the antenna apply equally to transmitting and receiving.

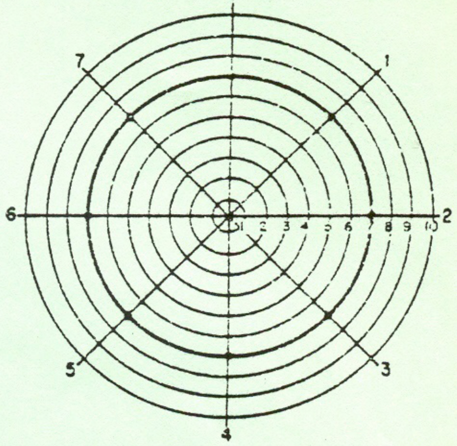




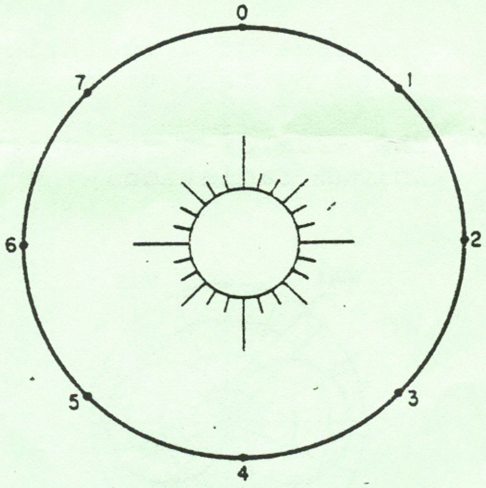
RADIATION RESISTANCE is the amount of resistance which, if inserted in place of the antenna, would consume the same amount of power that is actually radiated by the antenna.

RADIATION PATTERNS can be plotted on a rectangular- or polar-coordinate graph. These patterns are a measurement of the energy leaving an antenna.

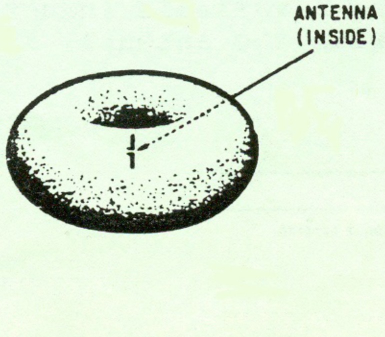




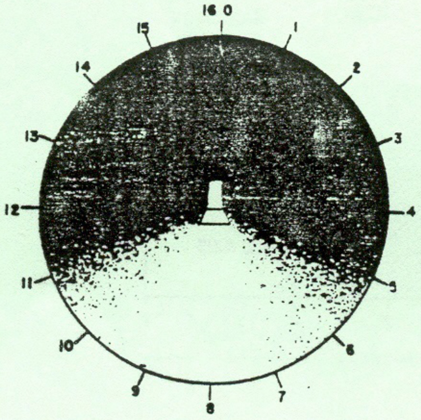
An ISOTROPIC RADIATOR radiates energy equally in all directions.



A HALF-WAVE ANTENNA(Hertz) consists of two lengths of rod or tubing, each a quarter-wave long at a certain frequency, which radiates a doughnut pattern.

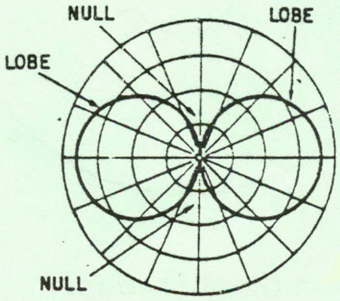


An ANISOTROPIC RADIATOR radiates energy directionally

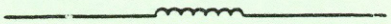


A LOBE is the area of a radiation pattern that is covered by radiation.

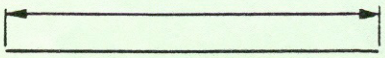
A NULL is the area of a radiation pattern that has minimum radiation.



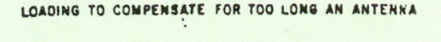
ANTENNA LOADING is the method used to change the electrical length of an antenna. This keeps the antenna in resonance with the applied frequency. It is accomplished by inserting a variable inductor or capacitor in series with the antenna.



LOADING TO COMPENSATE FOR TOO SHORT AN ANTENNA

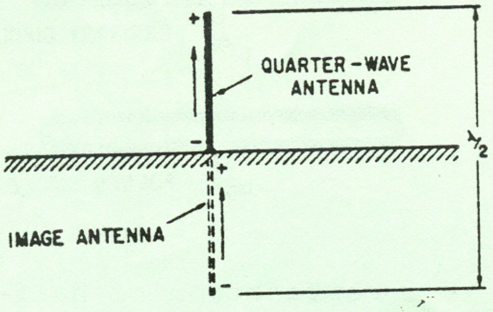


NORMAL ANTENNA, WITHOUT LOADING

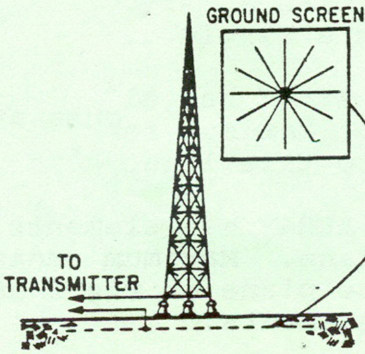


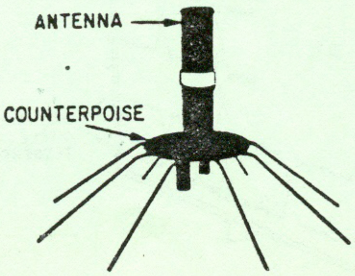
LOADING TO COMPENSATE FOR TOO LONG AN ANTENNA

A QUARTER-WAVE ANTENNA(Marconi) is a half-wave antenna cut in half with one end grounded. The ground furnishes the missing half of the antenna.

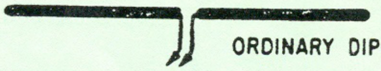


The GROUND SCREEN and the COUNTERPOISE are used to reduce losses caused by the ground in the immediate vicinity of the antenna. The ground screen is buried below the surface of the earth. The counterpoise is installed above the ground.

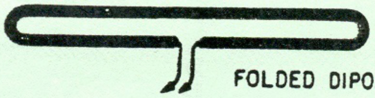




THE FOLDED DIPOLE consists of a dipole radiator which is connected in parallel at its ends to a half-wave radiator.



ORDINARY DIPOLE



FOLDED DIPOLE

AN ARRAY is a combination of half-wave elements operating together as a single antenna. It provides more gain and greater directivity than single element antennas.

A DRIVEN ARRAY derives its power directly from the source.

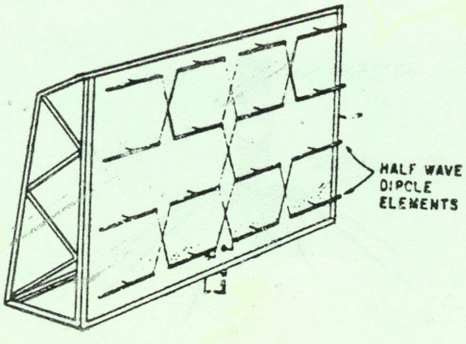
A PARASITIC ARRAY derives its power by coupling the energy from other elements of the antenna.

THE BIDIRECTIONAL ARRAY radiates energy equally in two opposing directions.

The UNIDIRECTIONAL ARRAY radiates energy efficiently in a single direction.

The COLLINEAR ARRAY has elements in a straight line. Maximum radiation occurs at right angles to this line.

The BROADSIDE ARRAY has elements parallel and in the same plane. Maximum radiation develops in the plane at right angles to the plane of the elements.

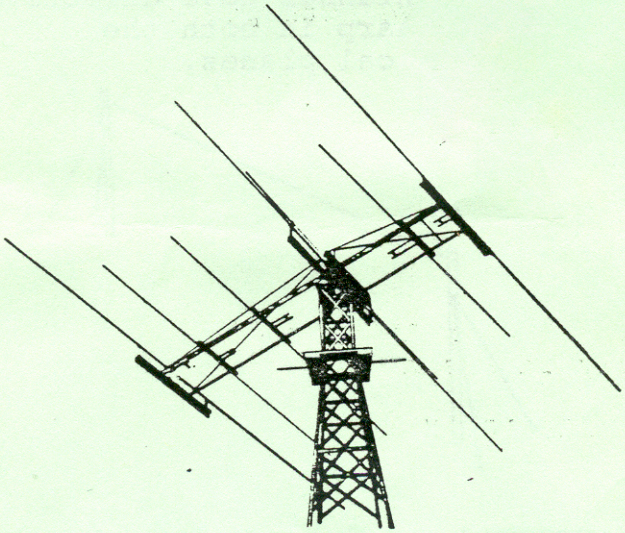


MATCHING STUBS are used between elements to maintain current in the proper phase.

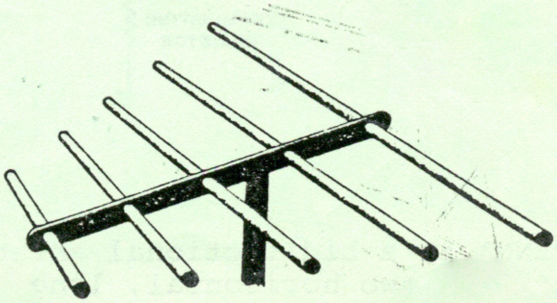
The GAIN OF A COLLINEAR ANTENNA is greatest when the elements are spaced from 0.4 to 0.5 wavelength apart or when the number of elements is increased.

THE OPTIMUM GAIN OF A BROADSIDE ARRAY is obtained when the elements are spaced 0.65 wavelength apart.

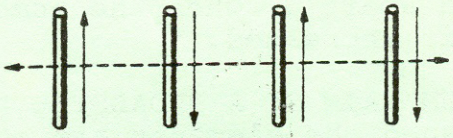
A PARASITIC ARRAY consists of one or more parasitic elements with a driven element. The amount of power gain and directivity depends on the lengths of the parasitic elements and the spacing between them.



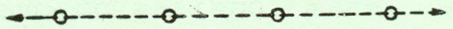
MULTIELEMENT ARRAYS, such as the YAGI, have a narrow frequency response as well as a narrow beamwidth.



The END-FIRE ARRAY has elements parallel to each other and in the same plane. Maximum radiation occurs along the axis of the array.

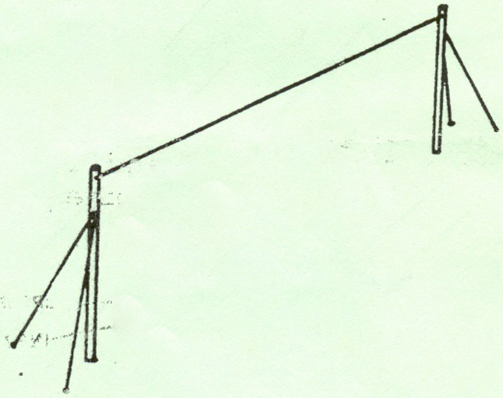


TOP VIEW OF ARRAY

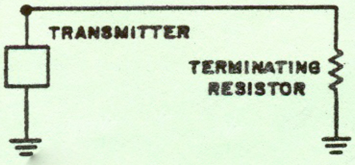


SIDE VIEW OF ARRAY

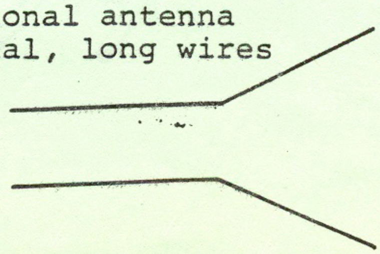
A LONG-WIRE ANTENNA is an antenna that is a wavelength or more long at the operating frequency. These antennas have directive patterns that are sharp in both the horizontal and vertical planes.



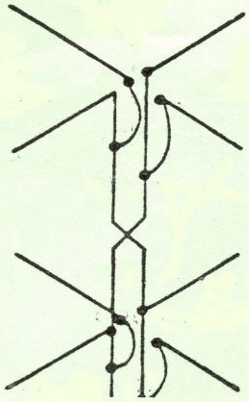
BEVERAGE ANTENNAS consist of a single wire that is two or more wavelengths long.



A V ANTENNA is a bidirectional antenna consisting of two horizontal, long wires arranged to form a V.



The TURNSTILE ANTENNA consists of two horizontal, half-wire antennas mounted at right angles to each other.



The RHOMBIC ANTENNA uses four conductors joined to form a rhombus shape. This antenna has a wide frequency range, is easy to construct and maintain, and is noncritical as far as operation and adjustment are concerned.